# TRIBOLOGICAL STUDIES OF DYNAMIC THERMAL SEAL MATERIALS

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# Contents of Discussion

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  - Description of Dynamic Thermal Barriers
  - Types/Construction of Dynamic Thermal Barriers
- Objectives and Approach
  - Project objectives
  - Tribometer upgrades and checkout
  - Test materials & test parameters
- Triobological Results
  - Previous results from NASP
  - Tribopairs (base materials and coatings)
  - Temperature
  - Load
- Summary, Conclusions, and Challenges

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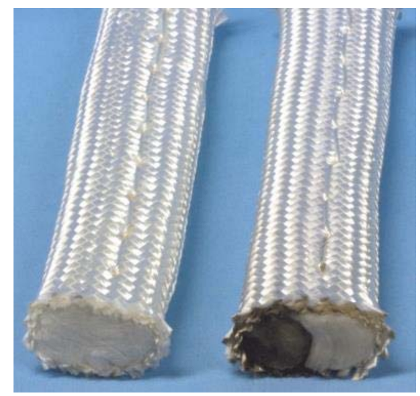
# An Integral Part of the TPS


**Fin Control Surfaces**

- Referred to as "dynamic thermal seals" or "dynamic seals"
- High-temp. ceramic-based materials
- Installed in TPS interface gaps between moving structures
- Roles
  - ➢ Thermal – limit inboard temperatures
  - ➢ Structural/physical – survive temps. and wear, not impede actuation/operation of control surface, accommodate deflections

**Body Flap**


**X38 CRV**



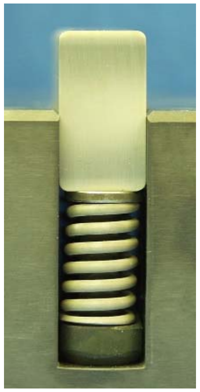
**Compliant Thermal Barriers (CTB's)**

# DYNAMIC THERMAL SEALS

Compliant Thermal Barrier

Rope Thermal Barrier

Hybrid Sheath Thermal Barrier



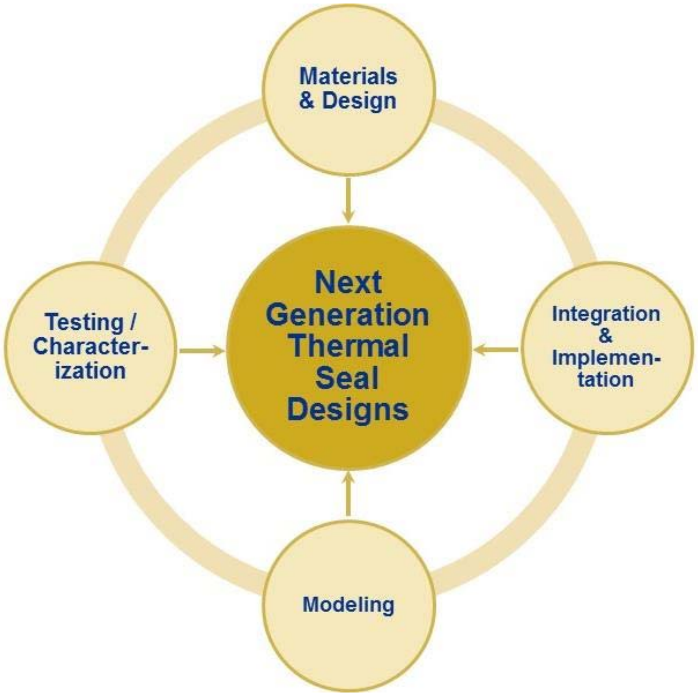
Wafer Seals

- Compliant Thermal Barriers (CTB)
  - Nextel™ sheath
  - Saffil® core, spring tube
  - Higher temps, lower stiffness, higher leakage
- Rope Thermal Barriers (RTB)
  - Nextel™ sheath
  - Fiber/fabric/rope core
  - Higher temps, higher stiffness, lower leakage
- Hybrid Sheath Thermal Barriers (HSTB)
  - Metalllic wire braid/Nextel™ sheath
  - Saffil®, fiber/fabric/rope core
  - Better wear resistance, lower temps
- Wafer Seals
  - Monolithic materials (metals, ceramics, etc.)
  - Low leakage (tight tolerences)
  - Require preloader

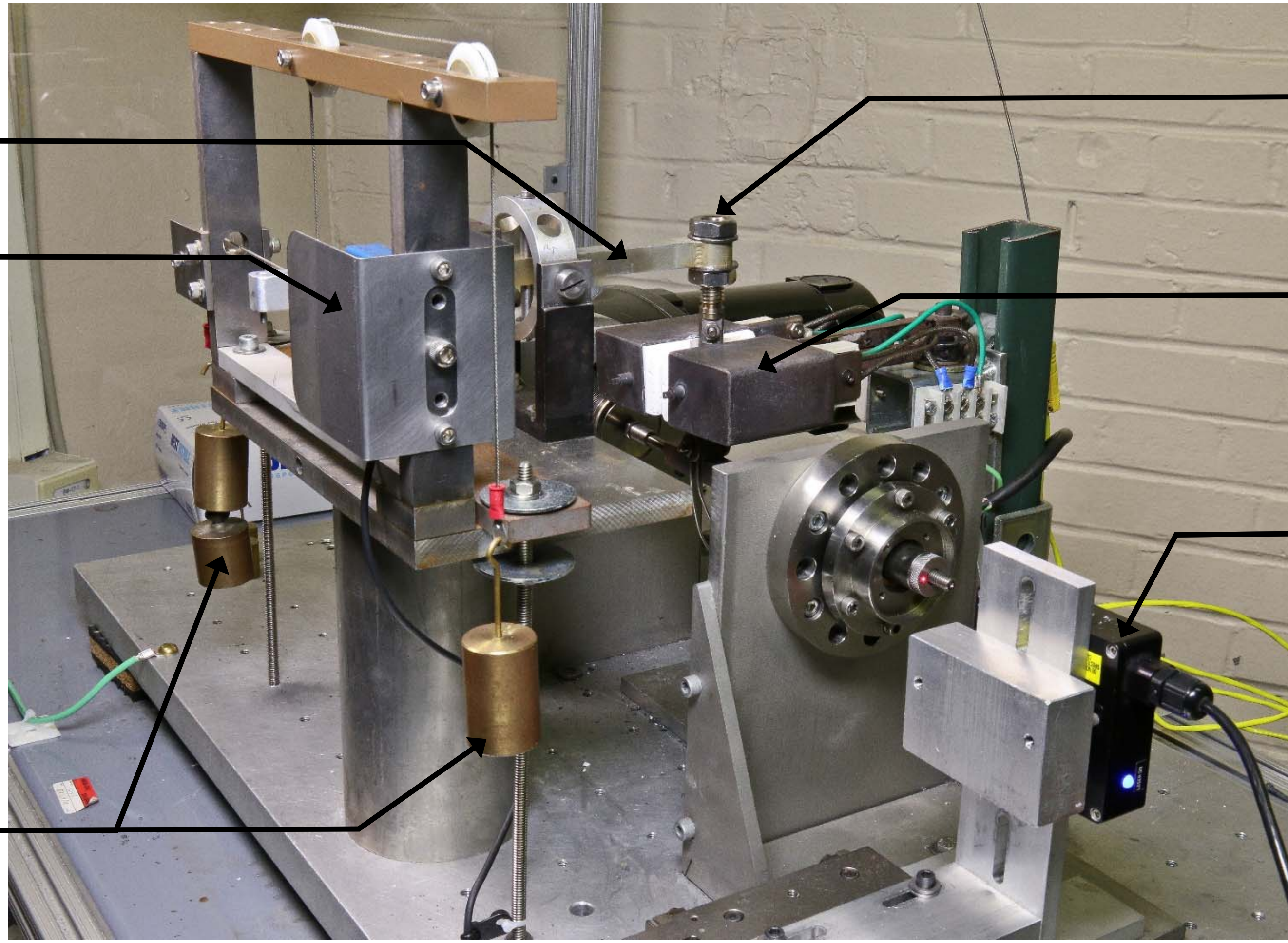
# OBJECTIVES

- Overall Objectives
  - Develop a repeatable screening tool to assess tribological performance of dynamic thermal barrier materials
  - Create a database of thermal barrier tribological performance (against TPS or propulsion materials)
  - Improve tribological performance of dynamic thermal barriers

- Dynamic thermal barrier triobological performance
  - Baseline performance against several materials
    - Metal
    - Non-ablative TPS
    - Ablative TPS
  - Effects of various parameters
    - Load
    - Temperature
    - Coatings



# High Temperature Tribometer Upgrades



# HIGH TEMPERATURE TRIBOMETER CHECKOUTS

| Test ID | Date | Pin | Plate | Normal Load | | Est. CoF, sliding | Published Data | Source |
|---|---|---|---|---|---|---|---|---|
| | | | | g | lbf | | | |
| 0.1 | 19-Aug | 304 SS | 304 SS | 200 | 0.39 | 0.18 | --- | --- |
| 0.2 | 20-Aug | 304 SS | 304 SS | 200 | 0.39 | 0.57 | 0.53 | ASM Handbook[1] |
| 0.3 | 20-Aug | 304 SS | 304 SS | 400 | 0.79 | 0.46 | 0.53 | ASM Handbook[1] |
| | | | | | | | | |
| 0.4 | 27-Aug | 4130 Steel | 4130 Steel | 200 | 0.39 | 0.42 | 0.40-0.60 | ASM Handbook[2], www.engineersedge.com |
| 0.5 | 28-Aug | 4130 Steel | 4130 Steel | 400 | 0.79 | 0.54 | 0.40-0.60 | ASM Handbook[2], www.engineersedge.com |
| 0.6 | 28-Aug | 4130 Steel | 4130 Steel | 400 | 0.79 | 0.46 | 0.40-0.60 | ASM Handbook[2], www.engineersedge.com |
| | | | | | | | | |
| 0.7 | 28-Aug | Teflon | 4130 Steel | 200 | 0.39 | 0.18 | 0.16 | ASM Handbook[3] |
| 0.8 | 28-Aug | Teflon | 4130 Steel | 400 | 0.79 | 0.17 | 0.16 | ASM Handbook[3] |
| | | | | | | | | |
| 0.9 | 28-Aug | Teflon | Teflon | 200 | 0.39 | 0.13 | 0.04-0.07 | ASM Handbook |
| 0.10 | 28-Aug | Teflon | Teflon | 200 | 0.39 | 0.13 | 0.04-0.07 | ASM Handbook |
| | | | | | | | | |
| N0.1 | 28-Aug | 4130 Steel | Nextel 312 | 100 | 0.19 | 0.65 | 0.50-0.60 | NASA TM 105199 |
| N0.2 | 28-Aug | 4130 Steel | Nextel 312 | 200 | 0.39 | 0.60 | 0.50-0.60 | NASA TM 105199 |

# High Temperature Wear-Resistant Coating Candidates

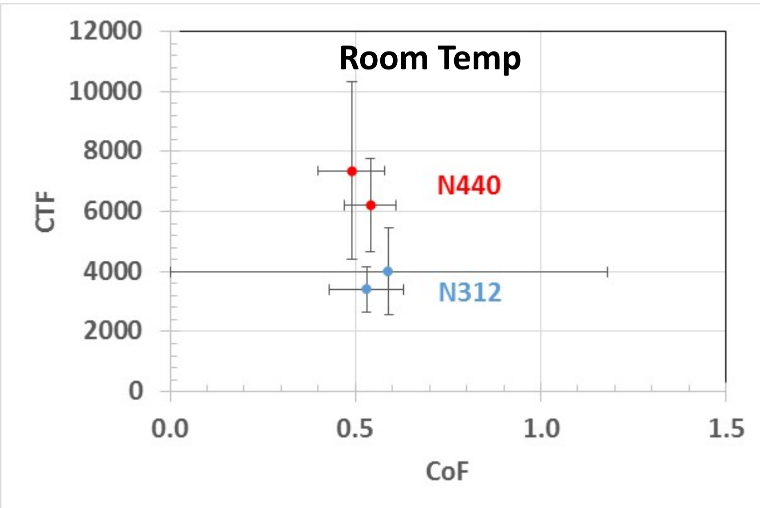
| Coating | Room Temp CoF | High Temp CoF | Max Tested Temp (°C/°F) | Predicted Max Thermal Stability (°C/°F) | Trade Study Weight |
|---|---|---|---|---|---|
| **NbN/Ag** | 0.35 | 0.27 | 1000/1832 | 1123/2053 | 297 |
| **Silver Tantalate ($AgTaO_3$)** | 0.60 | 0.06 | 750/1382 | 1172/2142 | 277 |
| **73 $TiO_2$– 27 $Cr_2O_3$** | 0.80 | 0.35 | 800/1472 | 1780/3236 | 272 |
| **100 $Cr_2O_3$** | 0.25 | 0.55 | 800/1472 | 1650/3002 | 283 |
| **Au/Cr** | 0.54 | 0.34 | 1000/1832 | 1000/1832 | 284 |
| **MAX phase $Ti_2AlC$** | 0.70 | 0.36 | 550/1022 | 1400/2552 | 261 |
| **MAX phase $Ti_3SiC_2$** | 0.60 | 0.62 | 550/1022 | 1400/2552 | 249 |
| **xo** | **0.5** | **0.5** | **1100** | **1200** | |
| **w** | **5** | **9** | **7** | **10** | |

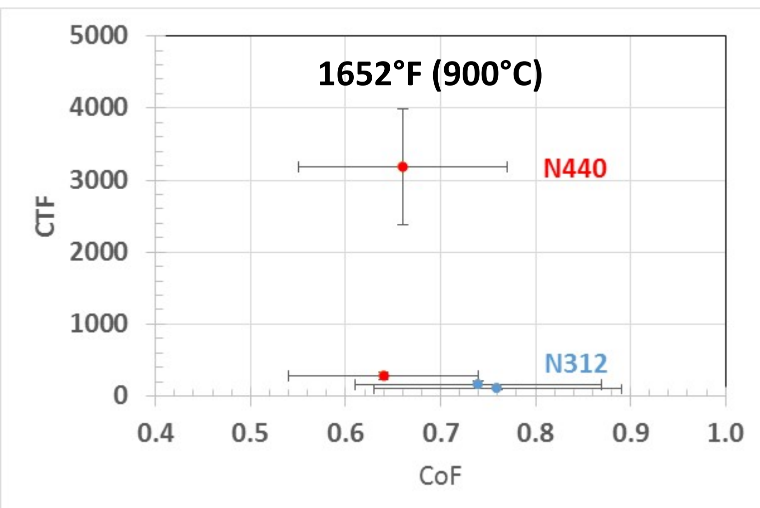
- Challenges with coatings – chemical compatibility/reactions, coating thickness, adherence
- Investigated a nanocomposite MAX phase type coating (SwRI Surface Engineering)

# TEST APPROACH

- Test Samples
  - Seal material: Nextel 312 (AF-20) and Nextel 440 (BF-20)
    - 5 harness satin weave
    - Warp: 30 threads per in.; Fill: 26 threads per inch
  - Fabric Coatings: None, TaSiN, TaSiCN (nano-composite coatings)
  - Wear surface: 4130 steel, AETB-8 tile, IN-625
- Test Parameters
  - Load: 2, 8 psi (14, 55 kPa)
  - Temperature: Ambient, 1500°F (Ambient, 815°C)
  - At least 3 tests were conducted for each tribopair at a given test condition

# WEAR RESULTS: PREVIOUS TESTING



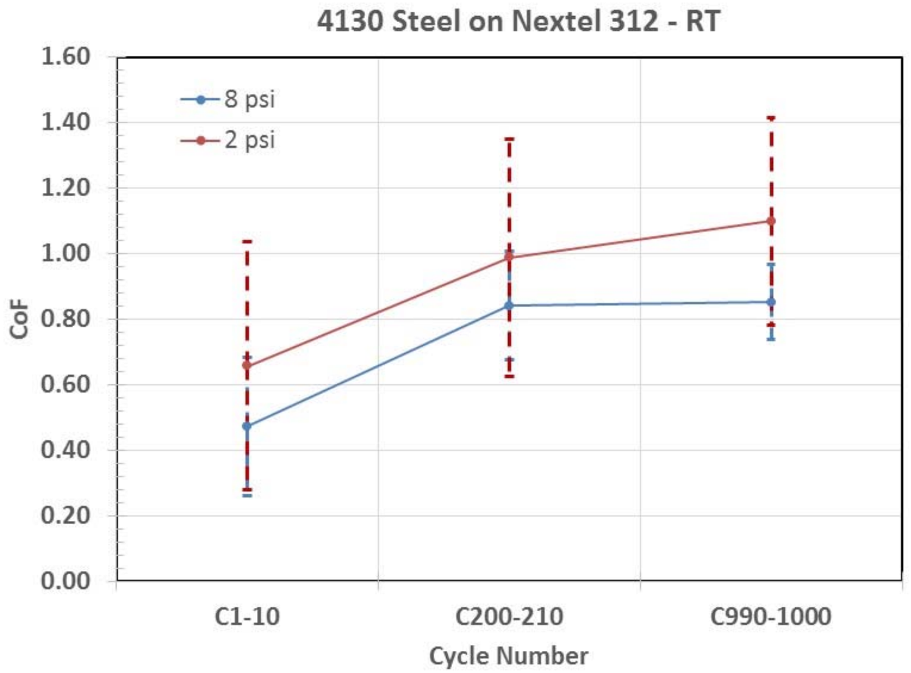



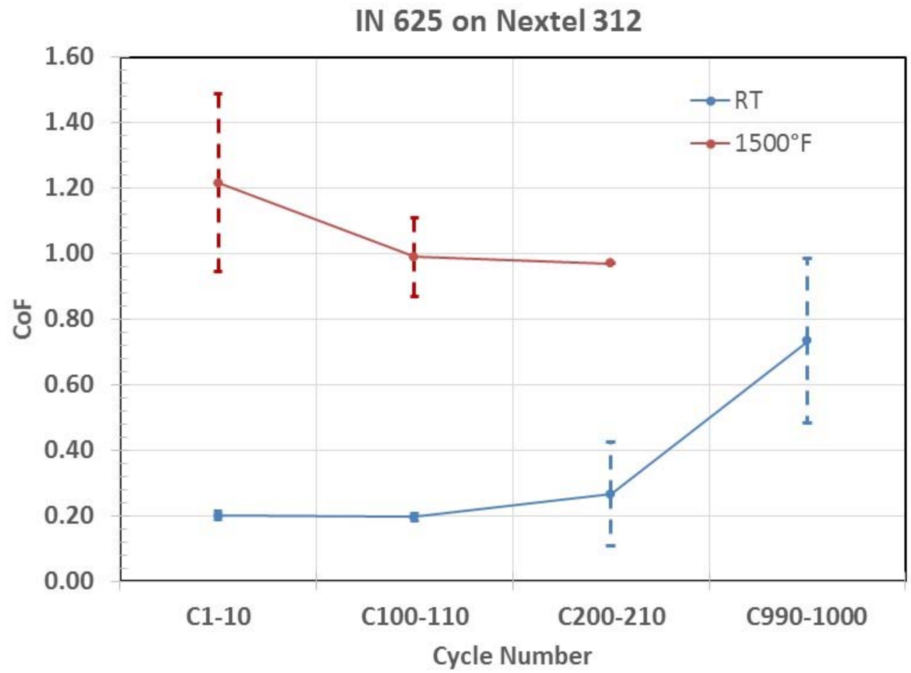

Dellacorte, C., *et al.* – Studies from 1988-1995

Approach
- Conducted numerous studies
- Pin-on-disk geometry (non-reciprocating)
- "Pin" materials: Nextel 312, Nextel 440, Nextel 550, Nextel 610
- Disk materials: IN 718, IN X-750, $Ti_3AlNb$
- Temperatures: Ambient - 1832°F (Ambient – 1000°C)
- Loads: 23 - 382 psi (160 - 2633 kPa)
- Coatings: Ag, CaF2, BN, Au

Results
- CTF generally decreased with increasing temperature (oxide-based fibers)
- CoF's: ~0.6 - 1.0

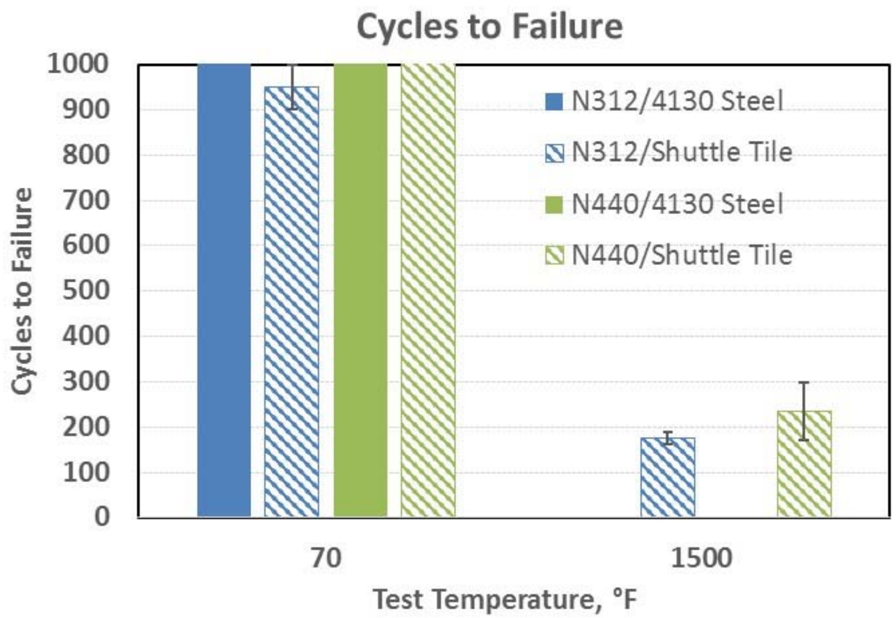
# WEAR RESULTS: EFFECT OF PRELOAD AND CYCLE NUMBER

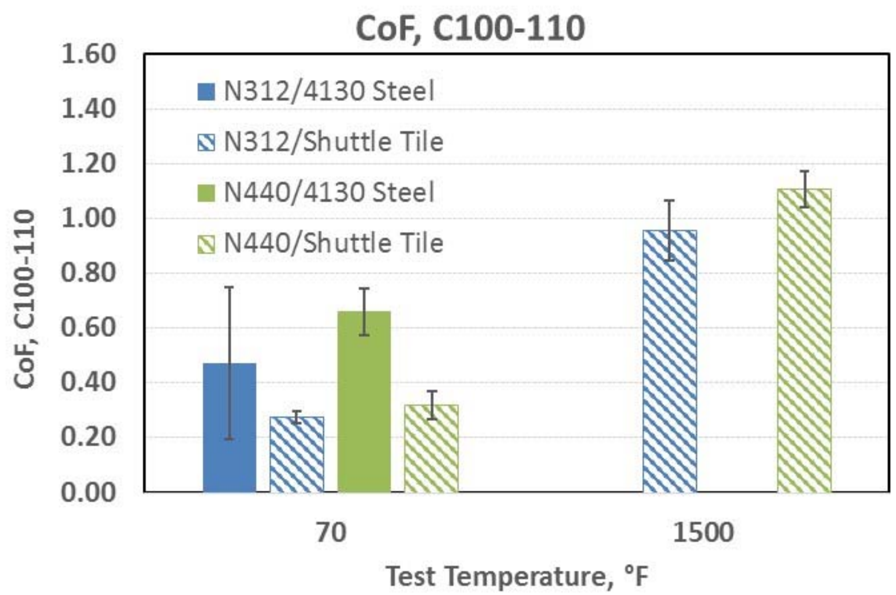



- CoF lower at higher preload, though likely not statistically significant
- At RT against 4130 steel, low initial CoF, than it increases
- At RT against IN-625, low initial CoF, than it increases
- At 1500°F, CoF was significantly higher starting off and then decreased to fairly high value

# WEAR RESULTS: TYPE OF NEXTEL




- Nextel 440 showed slight improvement over Nextel 312
  - Most evident against Shuttle tile
  - Higher CTF likely due to higher breaking strength of N440 (250 lb/in. vs. 150 lbf/in.)
- Shuttle tile exhibited lower CoF than 4130 steel
- CoF appeared to significantly increase for higher temperatures with these tribomaterials

# Wear Results: Type of Nextel

RT

1500°F

## Nextel 312

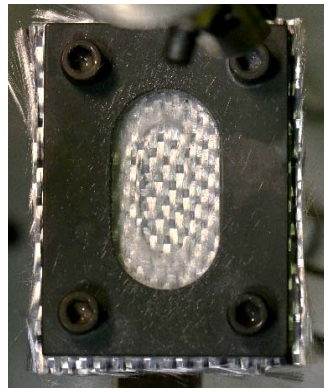
4130 Steel

Shuttle Tile

Shuttle Tile

## Nextel 440

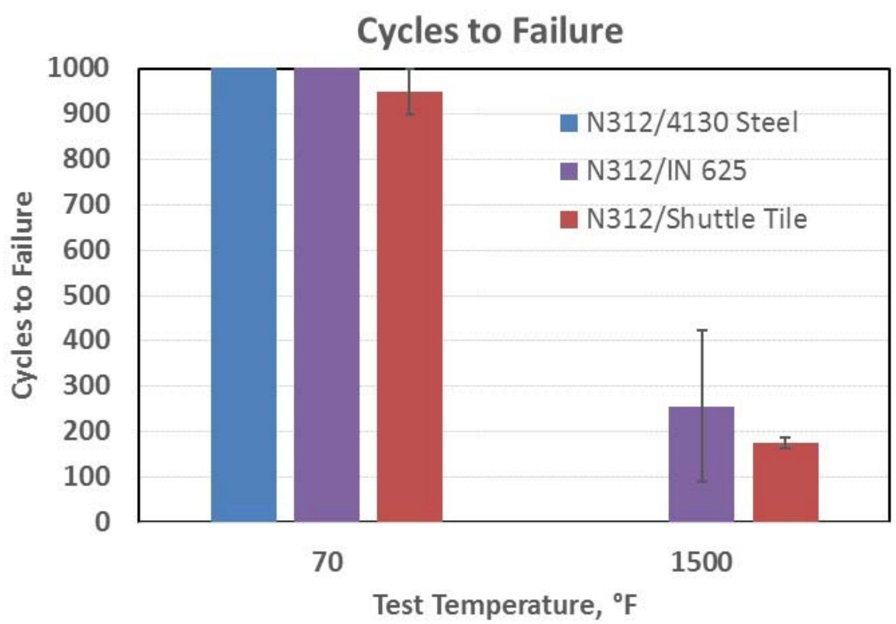
4130 Steel

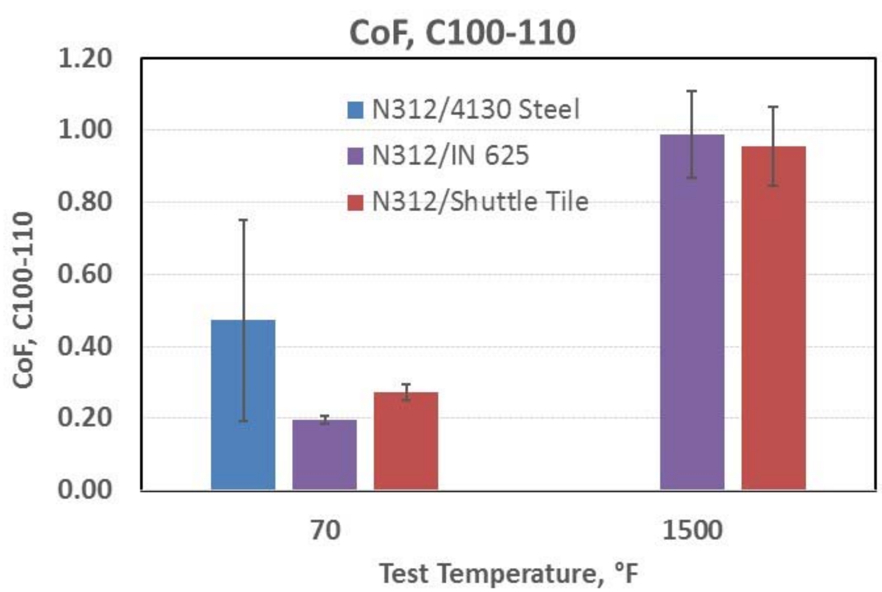


Shuttle Tile

Shuttle Tile

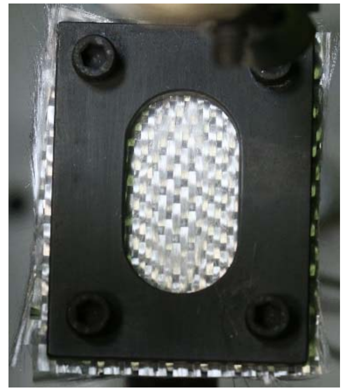
# WEAR RESULTS: PIN MATERIAL



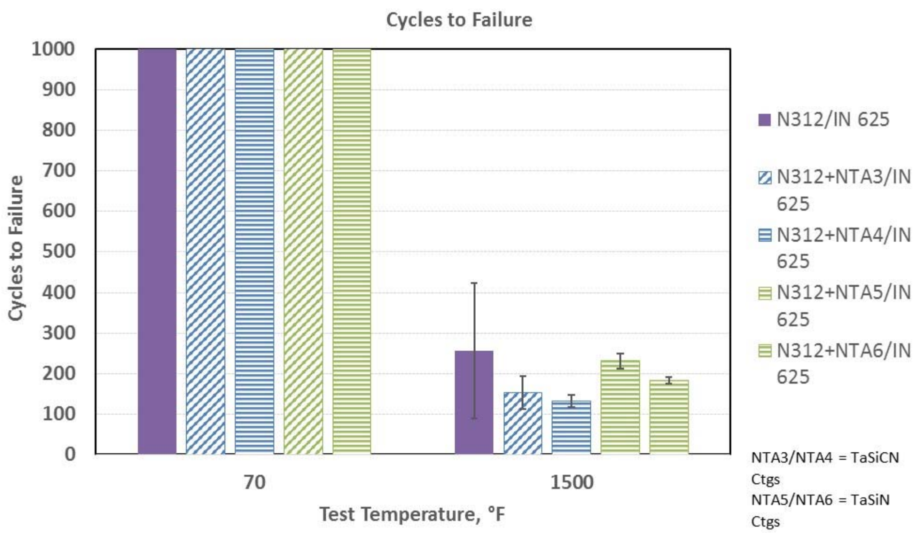



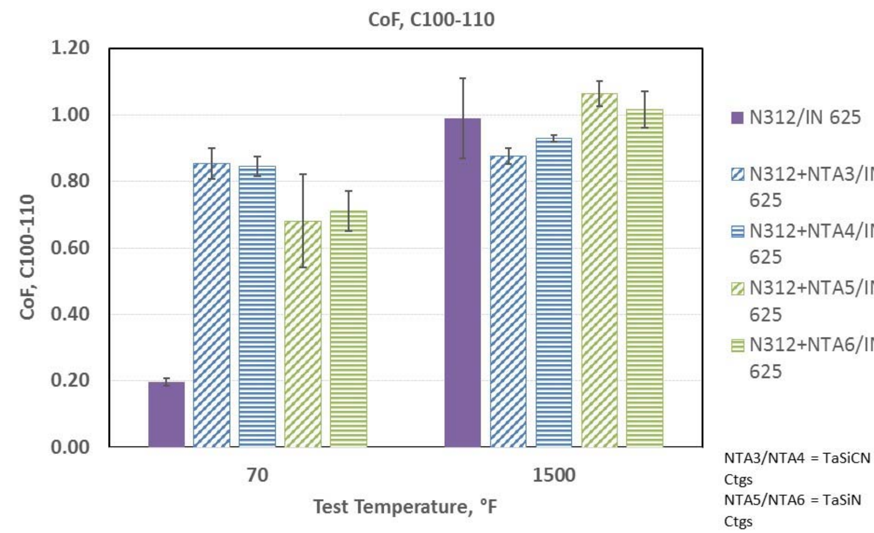

- Shuttle tile showed some difference when compared to metals
  - Slightly lower CTF
  - Most evident against Shuttle tile
- Shuttle tile exhibited lower CoF than 4130 steel
- CoF appeared to increase significantly with higher temperatures with these tribomaterials

# WEAR RESULTS: PIN MATERIAL

| | 4130 Steel | IN 625 | Shuttle Tile |
|---|---|---|---|
| RT |  |  |  |
| 1500°F | |  |  |

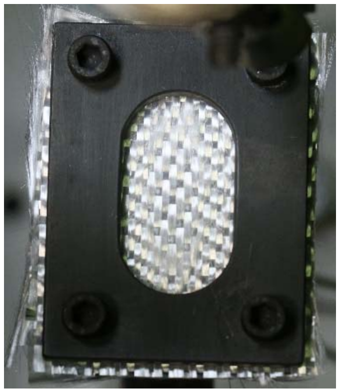
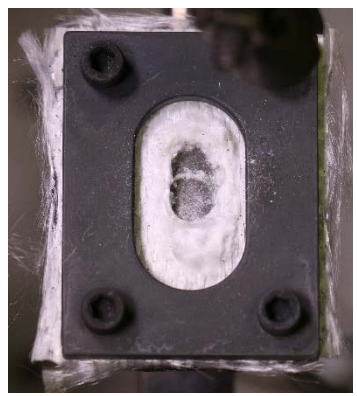
# WEAR RESULTS: EFFECT OF COATINGS




- No significant improvement in CTF with coatings
- Performance comparable (possibly slightly worse) than uncoated Nextel 312
- Possible coating adhesion issues and reactions with Nextel

# Wear Results: Effect of Coatings

| | N312 | N312 + NTA-3 | N312 + NTA-4 |
|---|---|---|---|
| **RT** |  |  |  |
| **1500°F** |  |  |  |

# Wear Results: Effect of Coatings

N312 | N312 + NTA-5 | N312 + NTA-6

RT

1500°F

# Summary, Conclusions, & Challenges

- Rig Upgrade
  - Improved instrumentation, modernized DAQ, augmented stroke length
  - Produced believable, reliable, repeatable results
  - Learned significant lessons to help in design of a newer higher-temperature rig
- Wear Performance of Nextel
  - Nextel durability insufficient for high temperature thermal barrier dynamic operation
    - Significant degradation in wear performance at high temperatures 1500°F
    - Require wear-resistant coatings
  - Initial tests of Nextel against TPS materials demonstrated poor wear resistance, even at room temperature
  - Preliminary tests with Ta-based nano-composite coatings showed no improvement
- Challenges
  - Coatings that are adherent, “non- reactive,” protective, low CoF
  - Coatings appear to work “better” when deposited on opposing wear surface
    - Most studies have deposited on metallic or ceramic substrates
    - Minimal evidence for success depositing on thermal barrier fabric materials

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